JPEG-2000 Progress Report: Multicomponent Imagery

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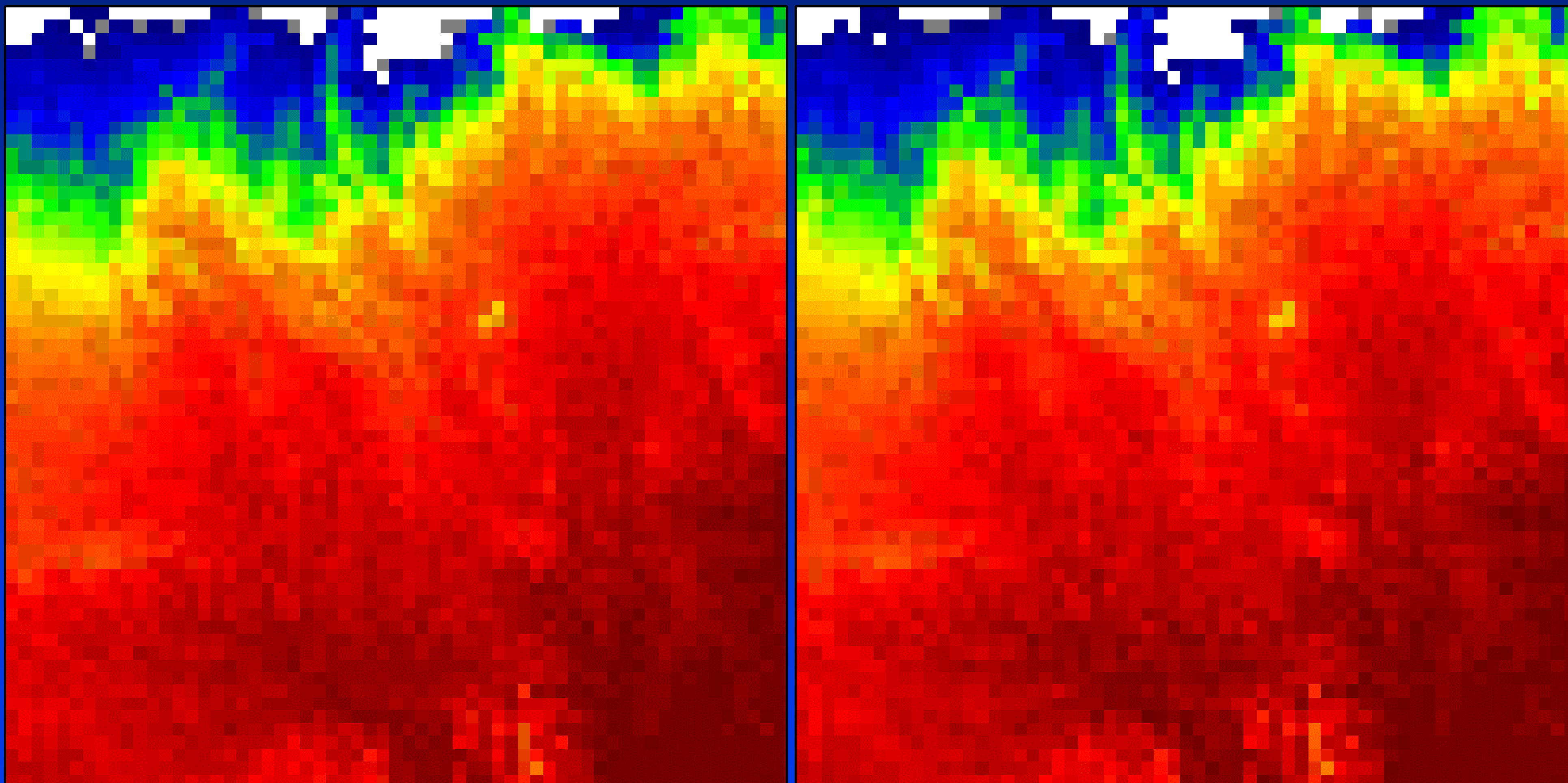
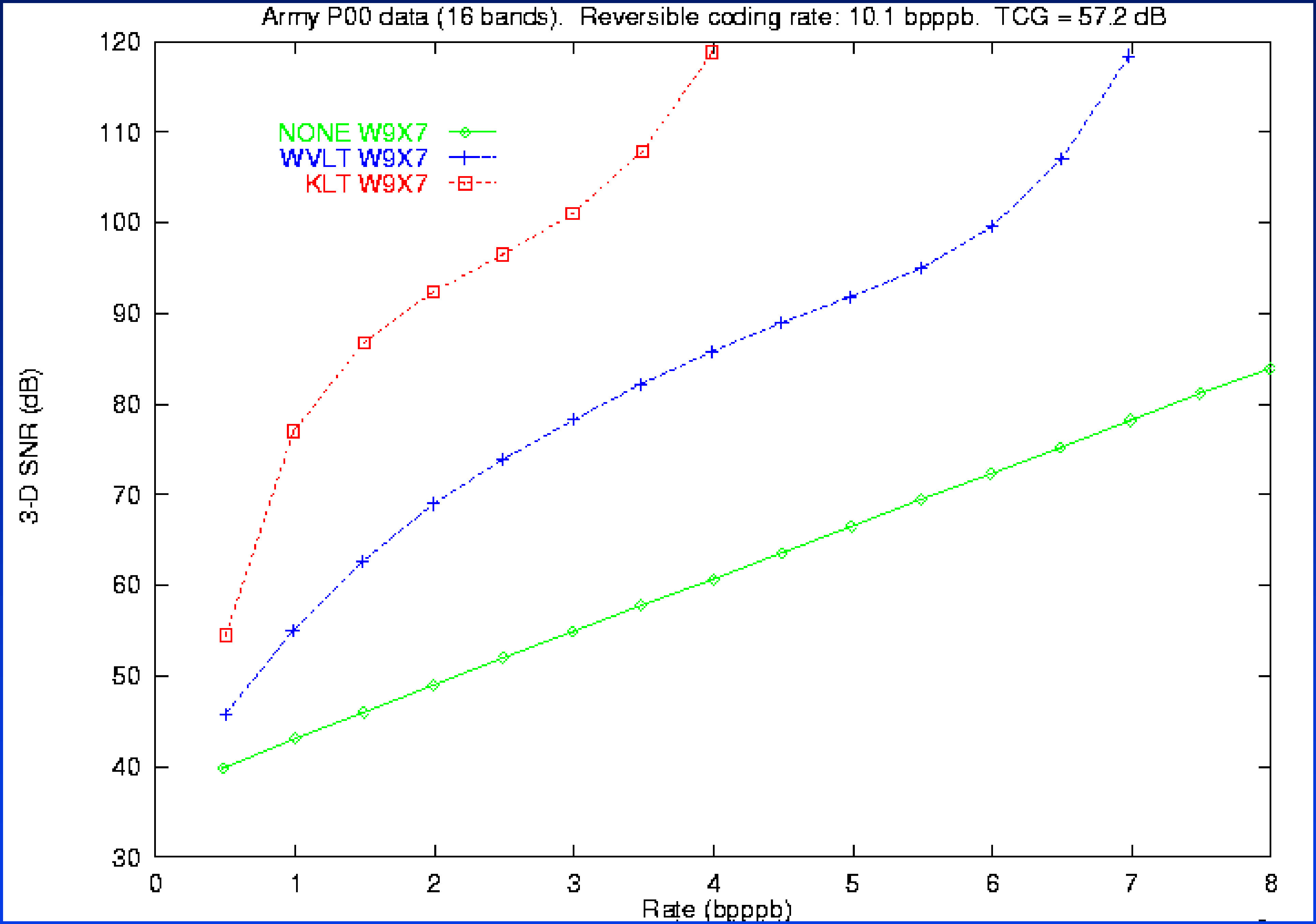
Summary of Experiments, Summer 2000

- Results based on VM 7.2, 8.0
- Bugs continue to be a problem:
  - VM does not run its guard bit calculation unless the -Fguard_bits flag is explicitly set on the VM_compress command line.
  - Apparent over/underflow problems with scalar quantizer parameters mu, epsilon when coding large numbers of decorrelated components. Is there a work-around? Do we need to increase the # bits used for these param's?
- Component decorrelation still not working on tomographic imagery.
- Need mechanism for signaling, implementing user-supplied filter banks for component decorrelation:
  - Spatial filter bank syntax is sufficient for signaling 2-channel filter banks.
  - Highly desirable to be able to signal non-symmetric filters for component decorrelation using same syntax to avoid having two separate, completely redundant types of marker segments for user-supplied filter banks.
  - Non-symmetric filters can be implemented by circular convolution.
- Still can't form single codestream based on multiple, low-dim'l KLT's.

Army Atmospheric Data (Volumetric), Pressure Field Cube (section)

- Original (L.); reconstructed from DWT decorrelation (R.) @ 0.5 bpppb





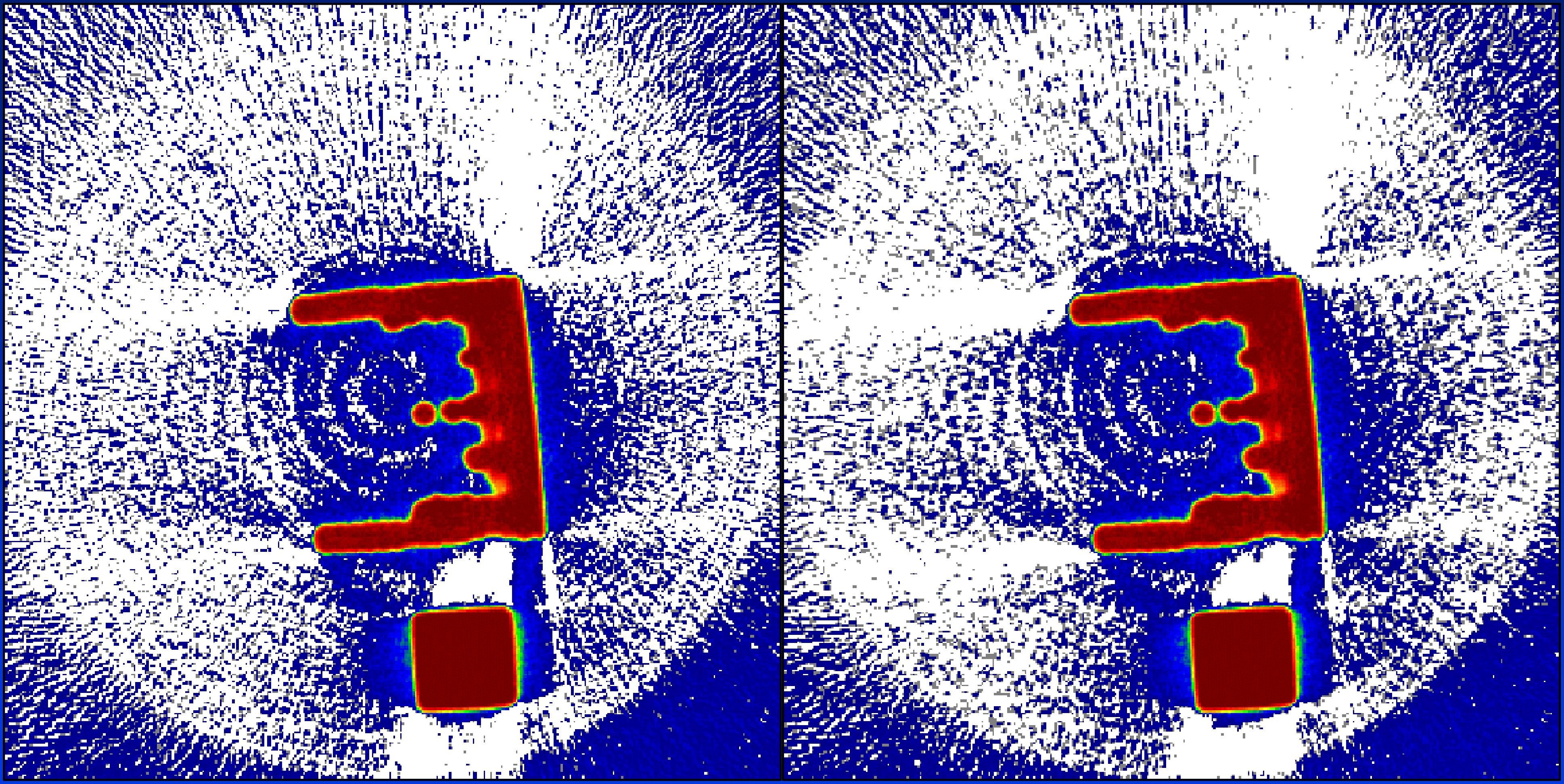
Army P00 data (16 bands). Reversible coding rate: 10.1 bpppb. TCG = 57.2 dB
NONE W9X7
WVLT W9X7
KLT W9X7
3-D SNR (dB)
Rate (bpppb)
120
110
100
90
80
70
60
50
40
30
0
1
2
3
4
5
6
7
8

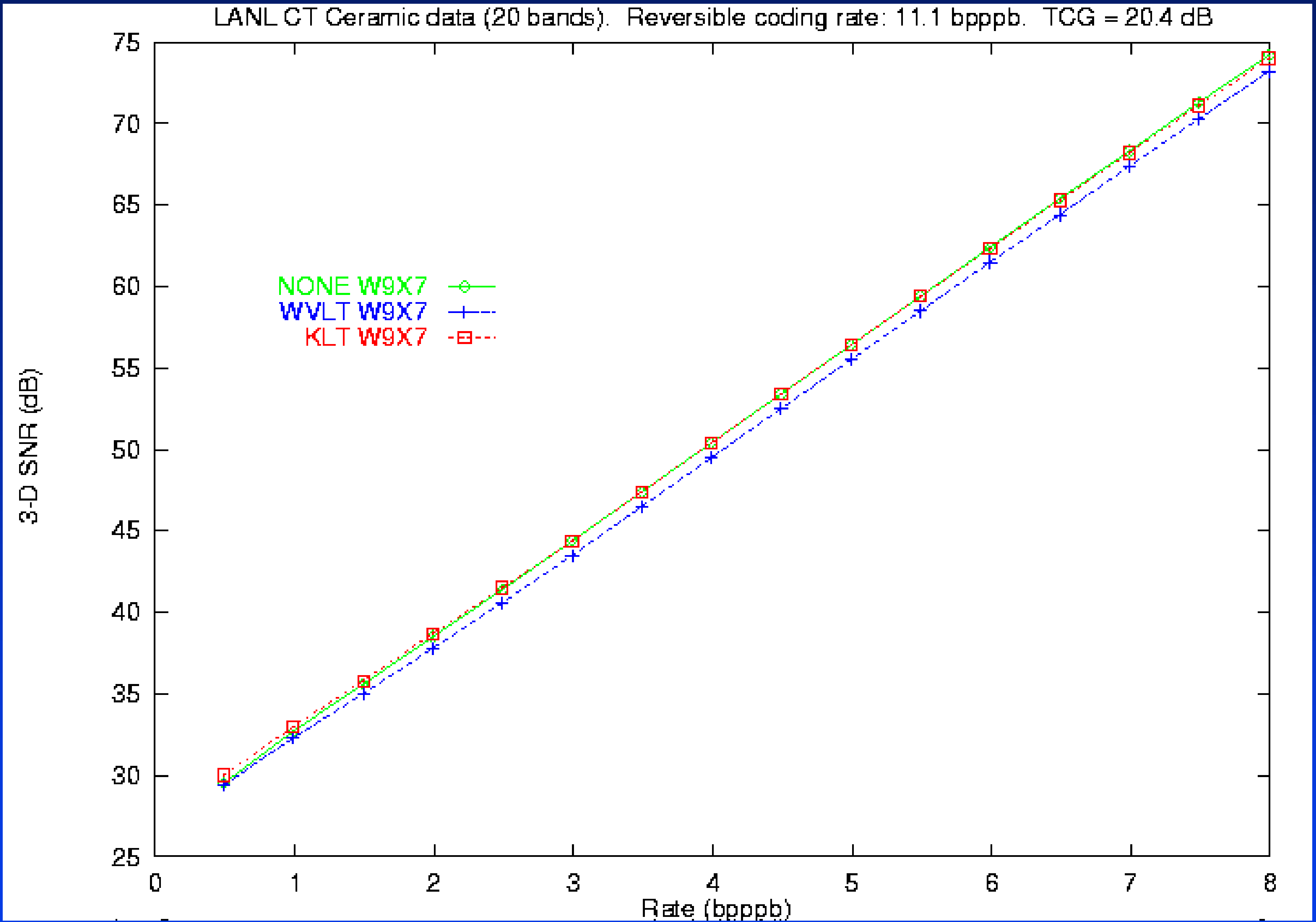
LANL "Industrial" CT Imagery

- 3-D volumetric computed tomographic imagery
- 16-bit unsigned data
- Noticeable numerical reconstruction noise, typical of CT imagery
- Variety of different (non-medical) subjects:
  - Industrial ceramic parts (product inspection)
  - Simulated high explosives (examining for defects)
  - Intricate machinery (reverse-engineering; product inspection)

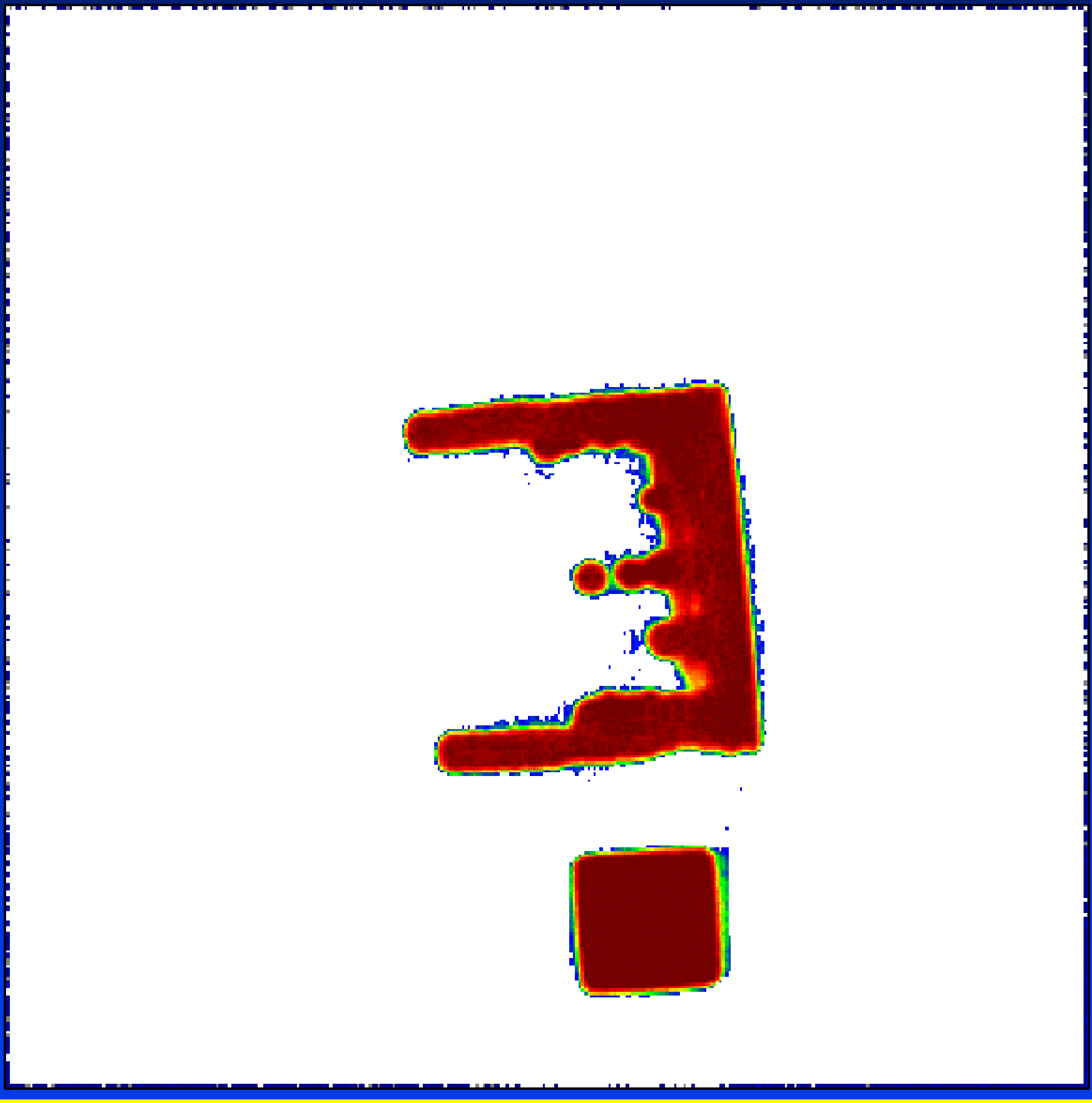
CT "Ceramic" Data

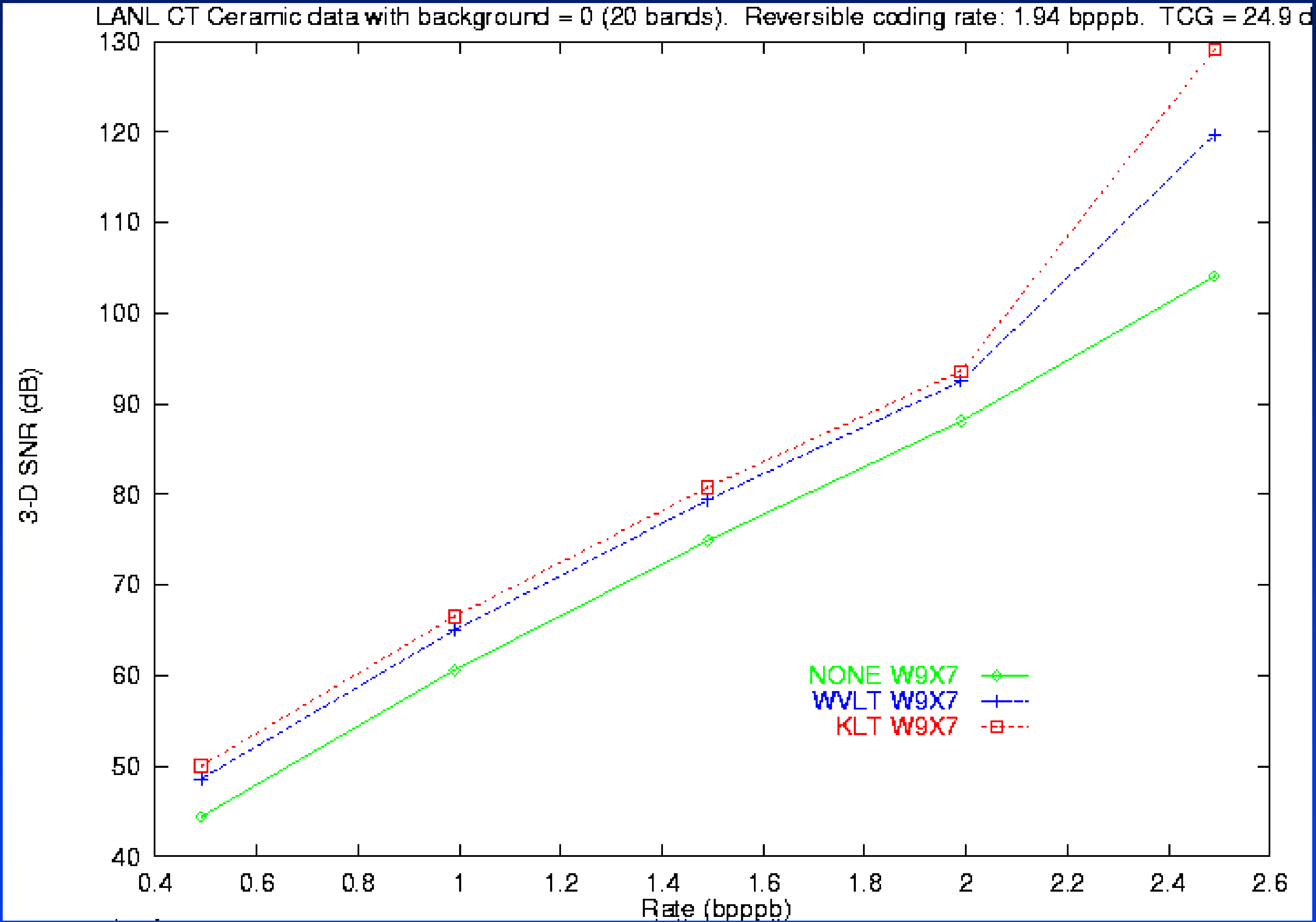
Original 16-bit CT data | **DWT/JPEG-2000, 0.5 bpppb**



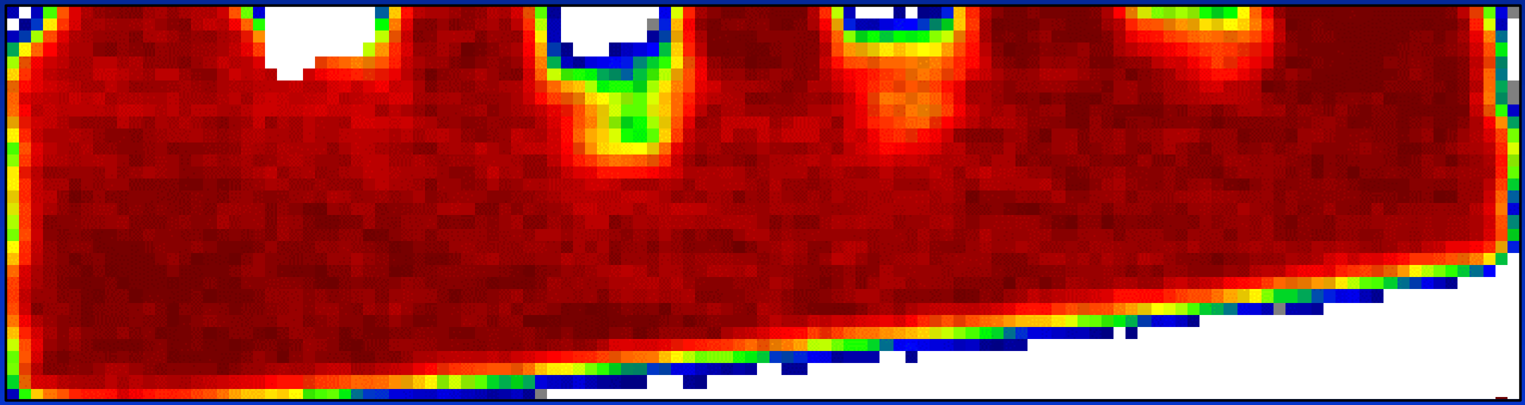

LANL CT Ceramic data (20 bands). Reversible coding rate: 11.1 bppppb. TCG = 20.4 dB
3-D SNR (dB)
Rate (bppppb)
NONE W9X7
WVLT W9X7
KLT W9X7
75
70
65
60
55
50
45
40
35
30
25
0
1
2
3
4
5
6
7
8

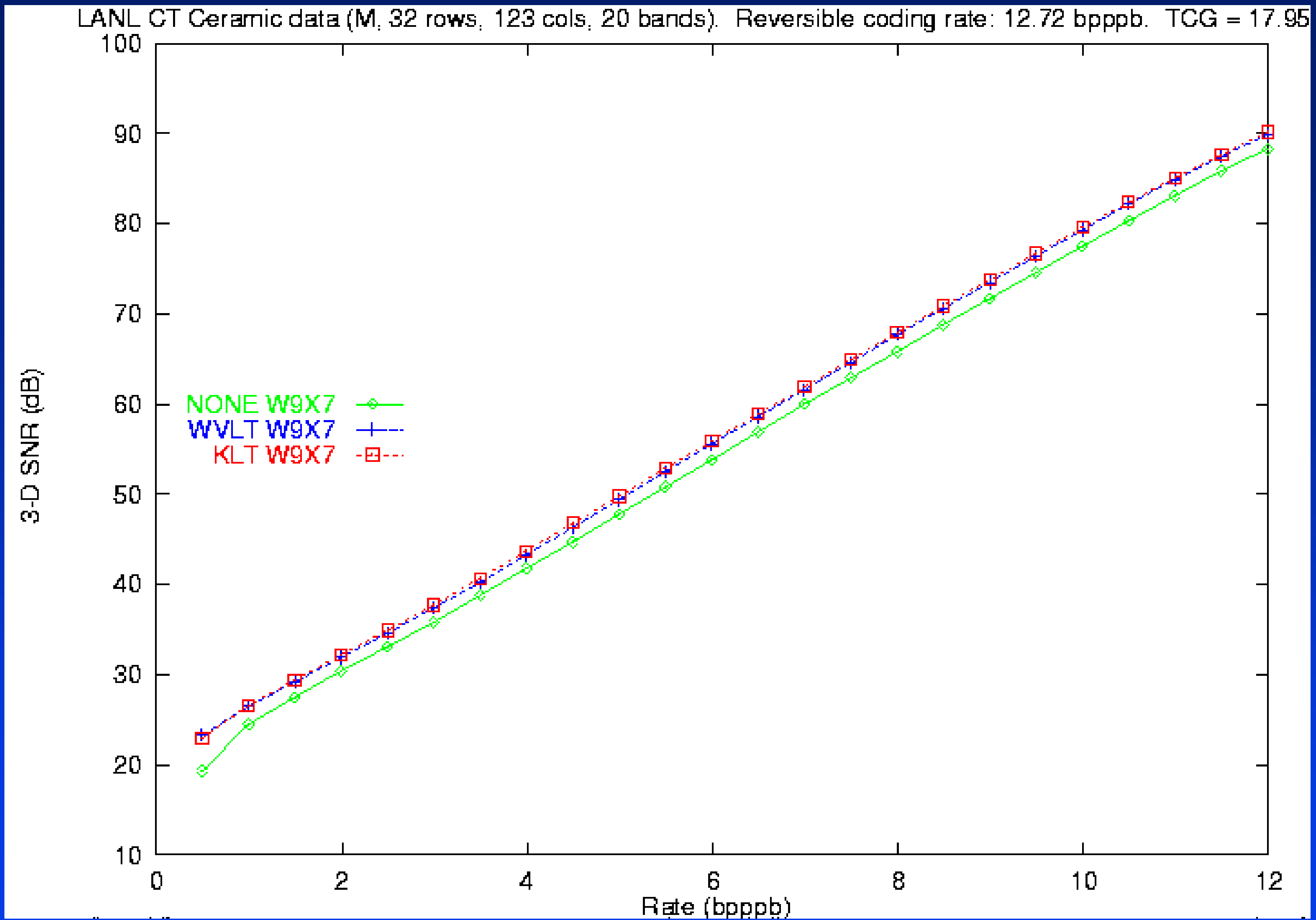
Ceramic Data, Background Masked and Zeroed Out




LANL CT Ceramic data with background = 0 (20 bands). Reversible coding rate: 1.94 bppppb. TCG = 24.9 d
3-D SNR (dB)
130
120
110
100
90
80
70
60
50
40
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
Rate (bpppb)
NONE W9X7
WVLT W9X7
KLT W9X7

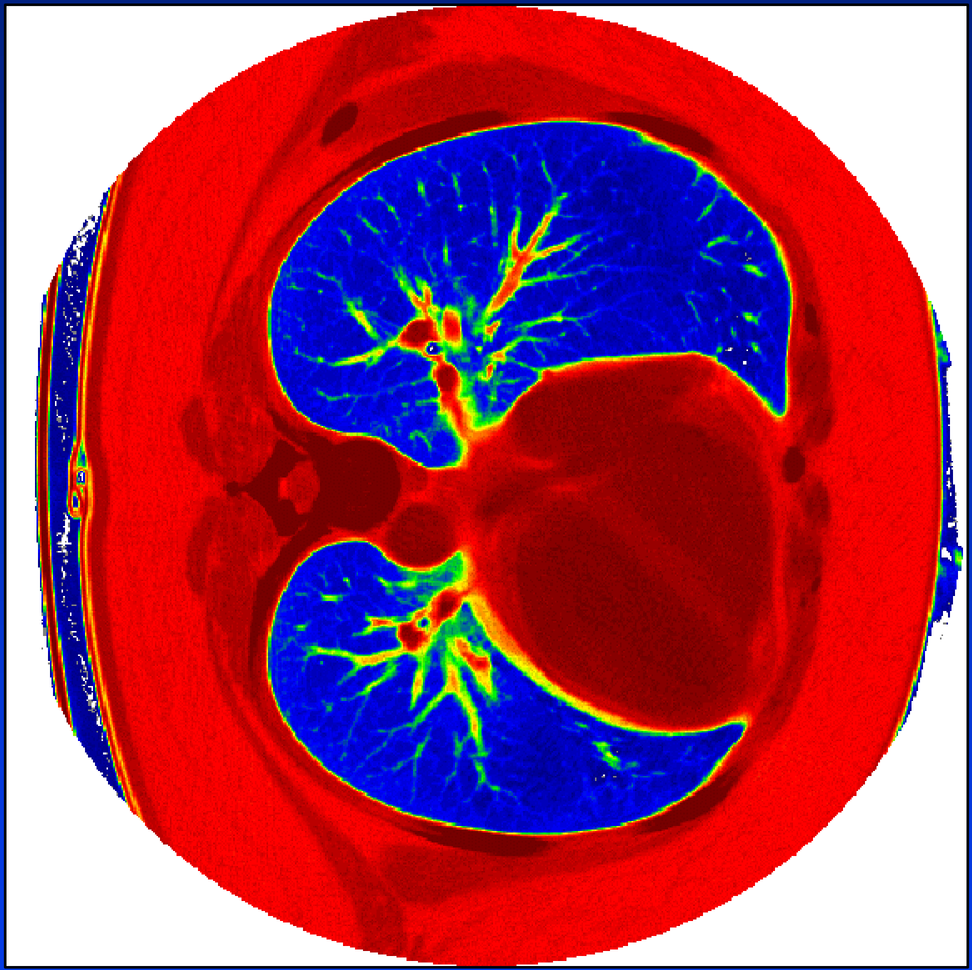
Ceramic Data, Cropped Detail Region

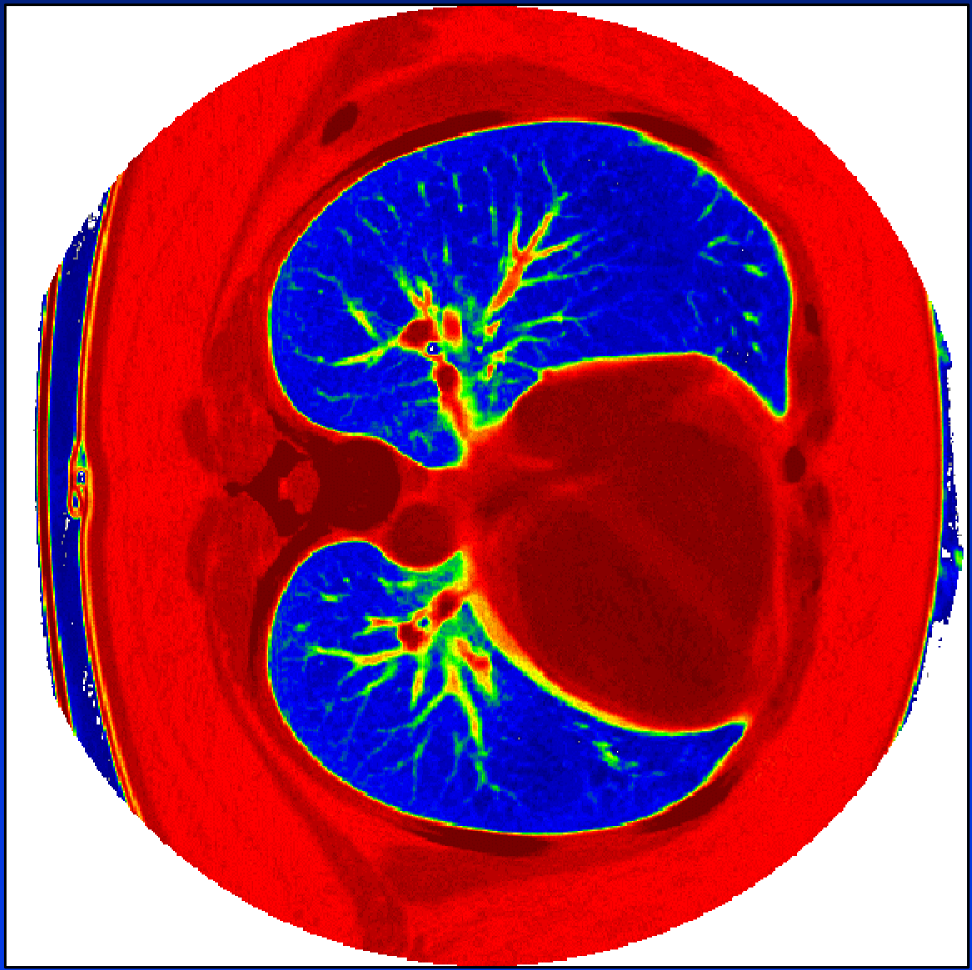


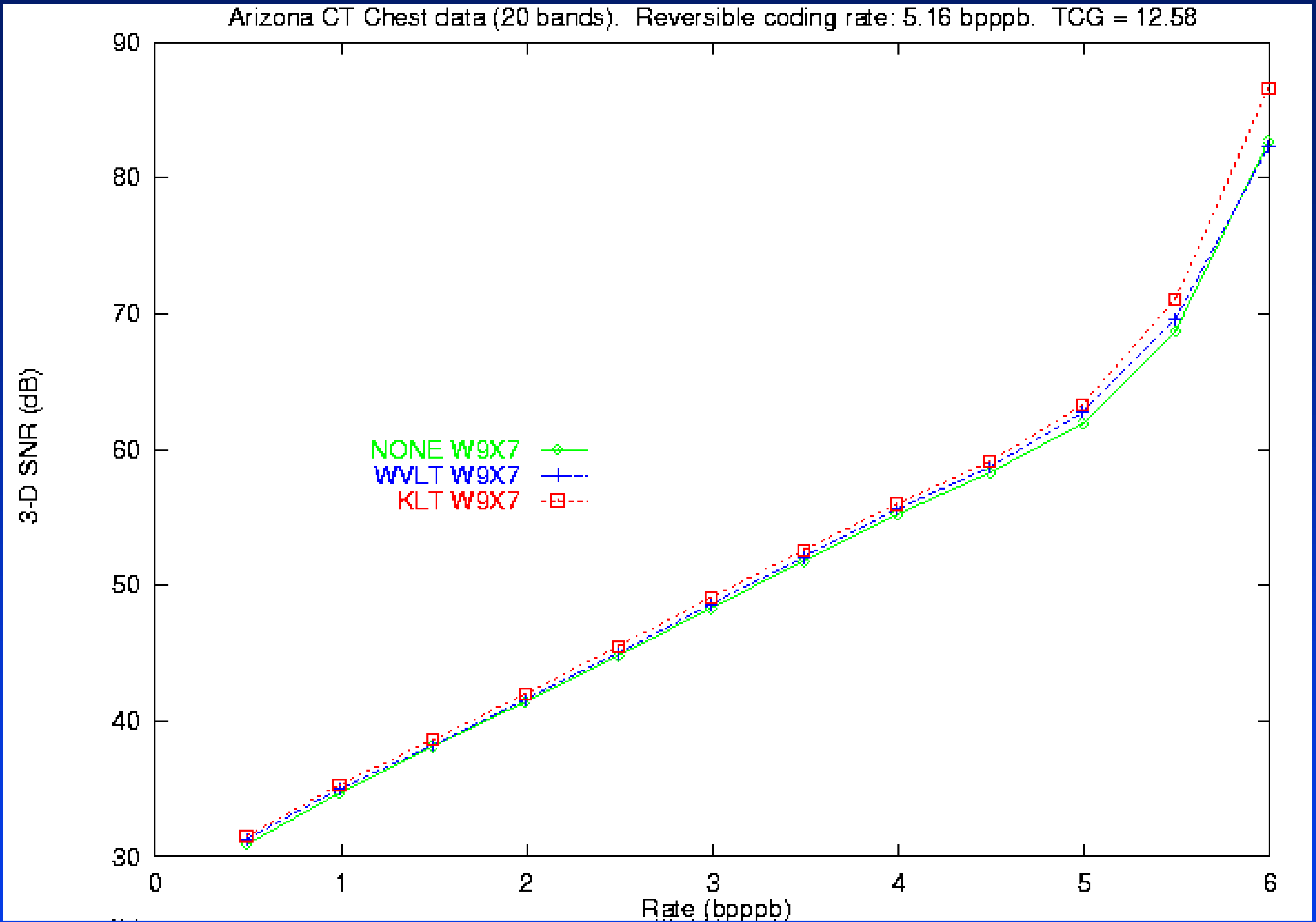

LANL CT Ceramic data (M, 32 rows, 123 cols, 20 bands). Reversible coding rate: 12.72 bpppb. TCG = 17.95
3-D SNR (dB)
Rate (bpppb)
NONE W9X7
WVLT W9X7
KLT W9X7
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12

Univ. of Arizona Chest Image

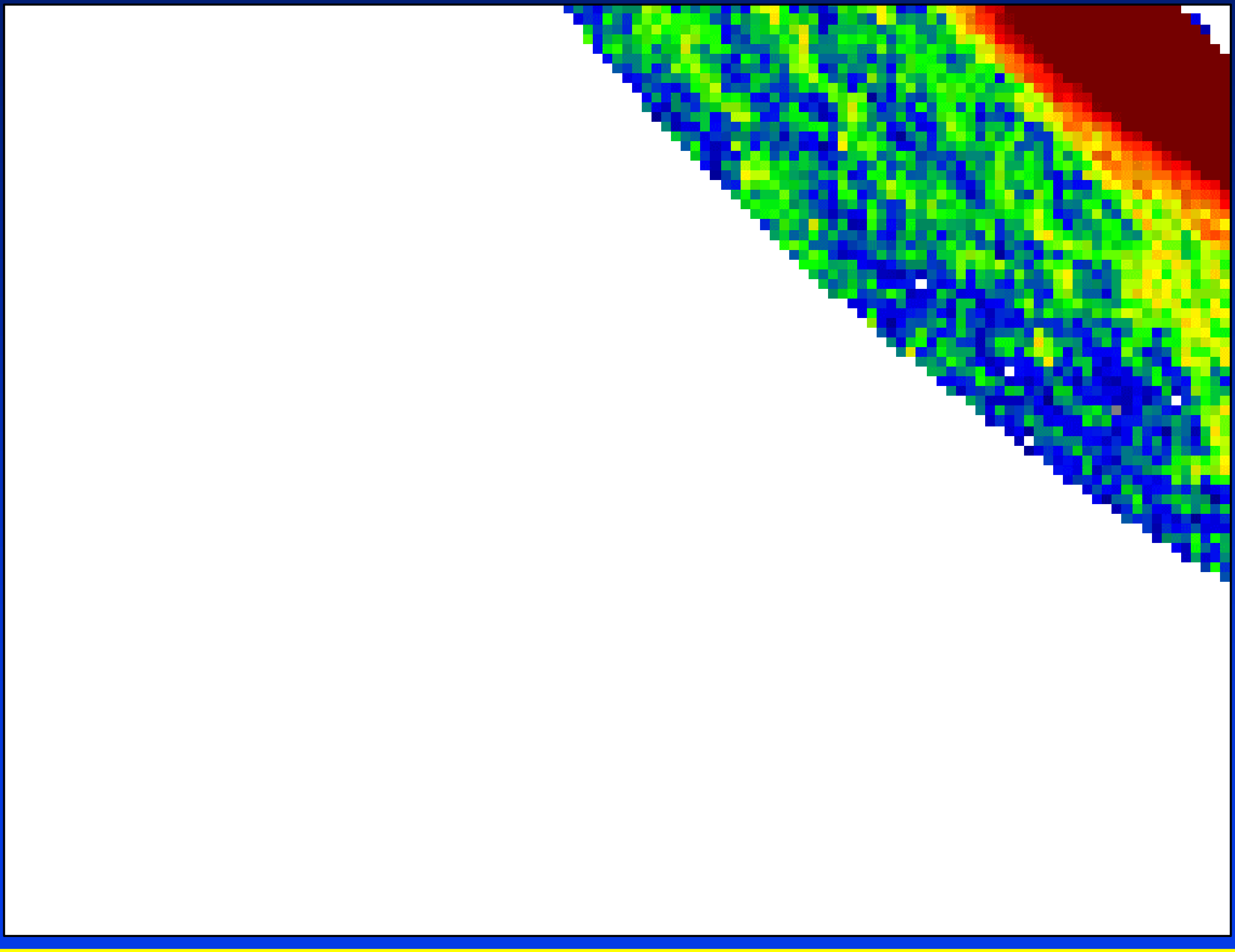
- **Original (L.); DWT decorrelation (R.) @ 0.5 bpppb**

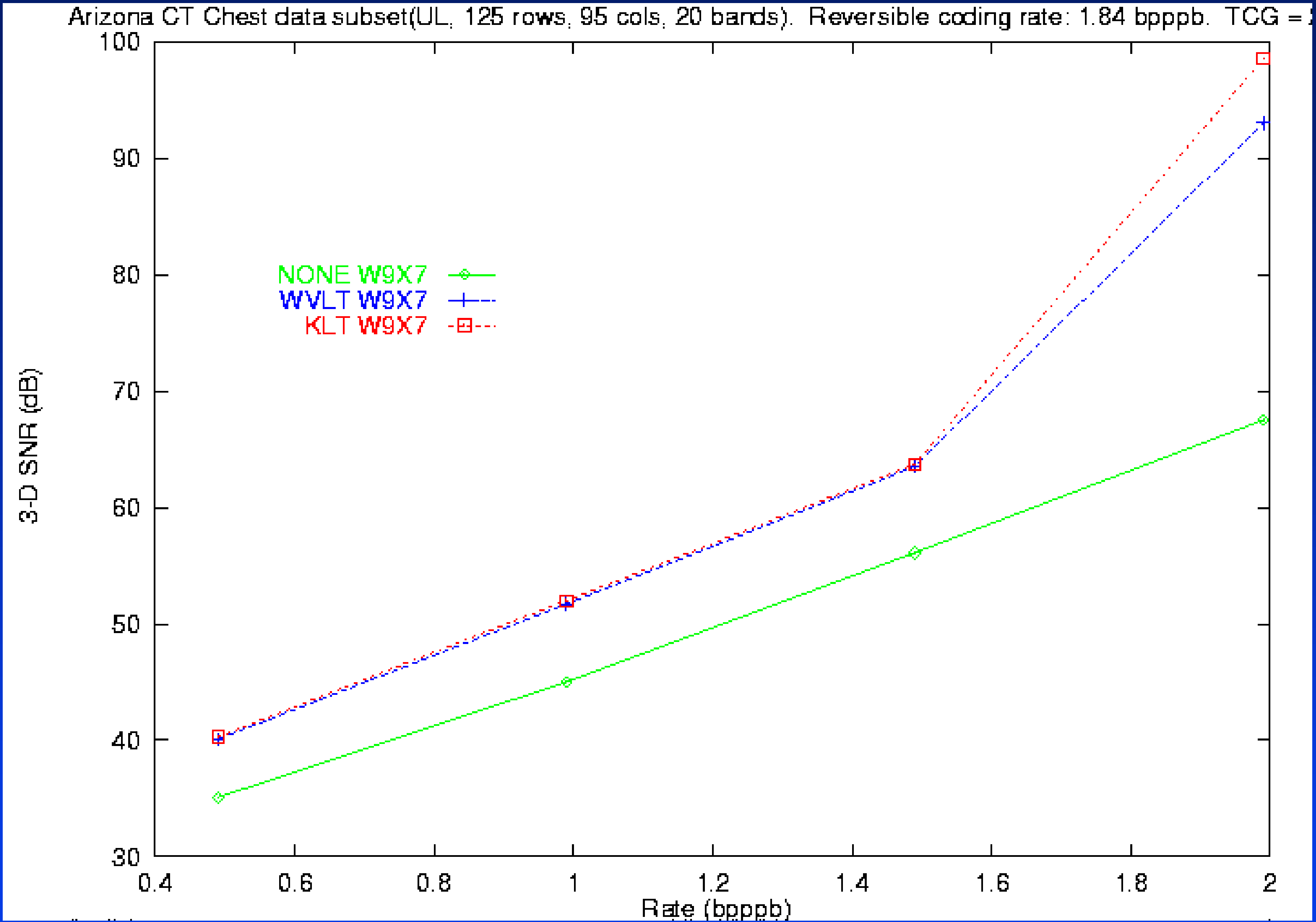




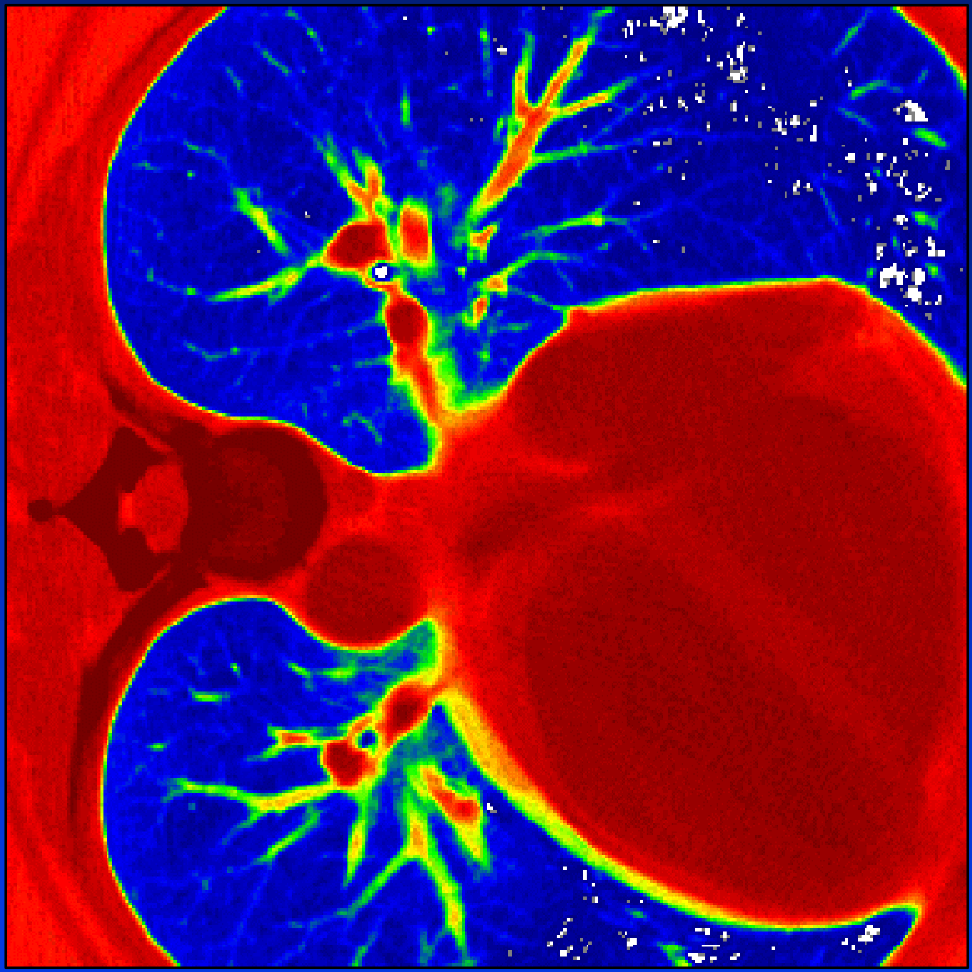

Arizona CT Chest data (20 bands). Reversible coding rate: 5.16 bpppb. TCG = 12.58
3-D SNR (dB)
Rate (bpppb)
NONE W9X7
WVLT W9X7
KLT W9X7
90
80
70
60
50
40
30
0
1
2
3
4
5
6

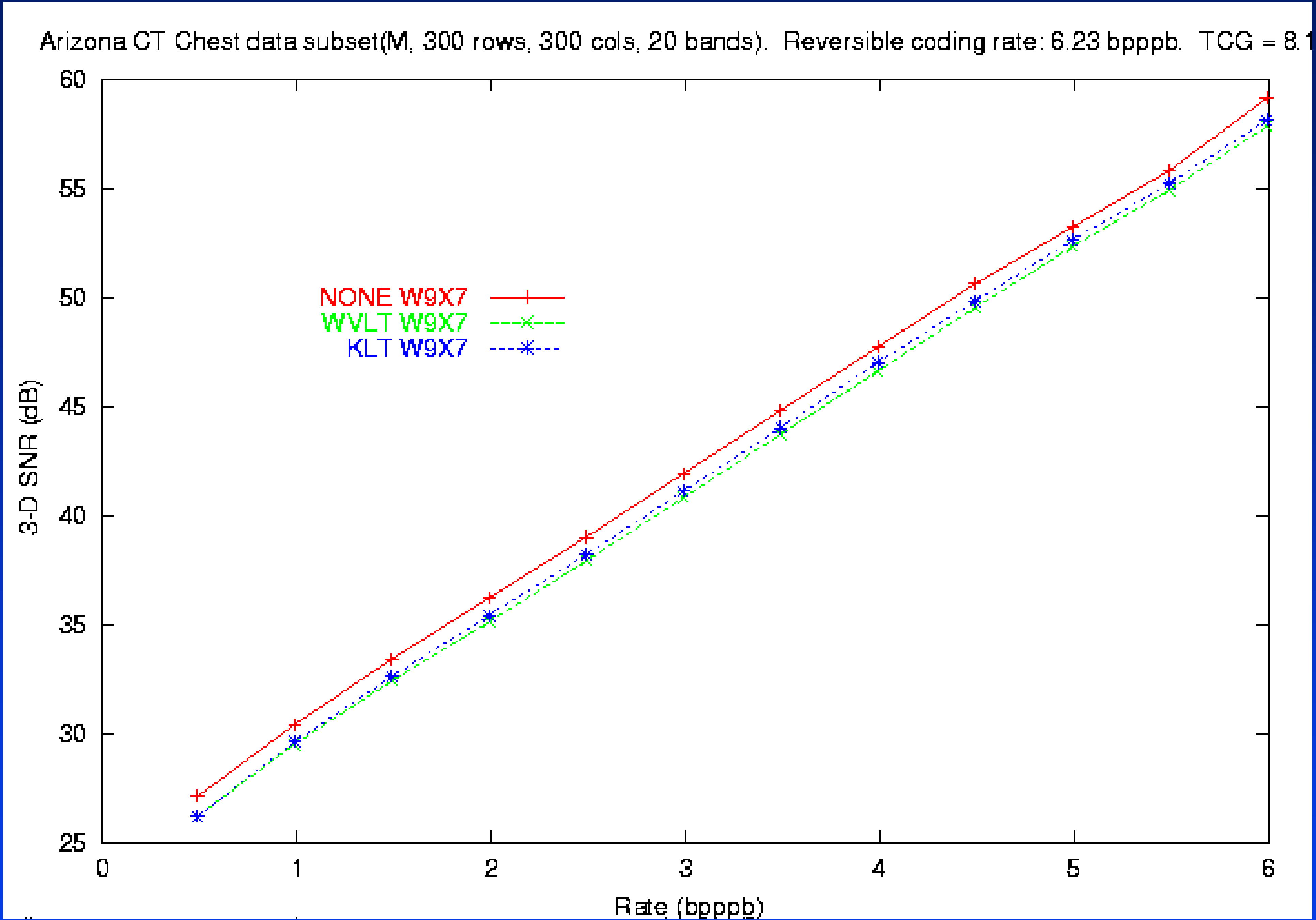
Crop a Region with More (noiseless) Background




Arizona CT Chest data subset(UL, 125 rows, 95 cols, 20 bands). Reversible coding rate: 1.84 bpppb. TCG =
3-D SNR (dB)
Rate (bpppb)
NONE W9X7
WVLT W9X7
KLT W9X7
100
90
80
70
60
50
40
30
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Crop a Region with No Background




Arizona CT Chest data subset(M, 300 rows, 300 cols, 20 bands). Reversible coding rate: 6.23 bpppb. TCG = 8.1
3-D SNR (dB)
Rate (bpppb)
NONE W9X7
WVLT W9X7
KLT W9X7
60
55
50
45
40
35
30
25
0
1
2
3
4
5
6

Conclusions re: Volumetric Imagery

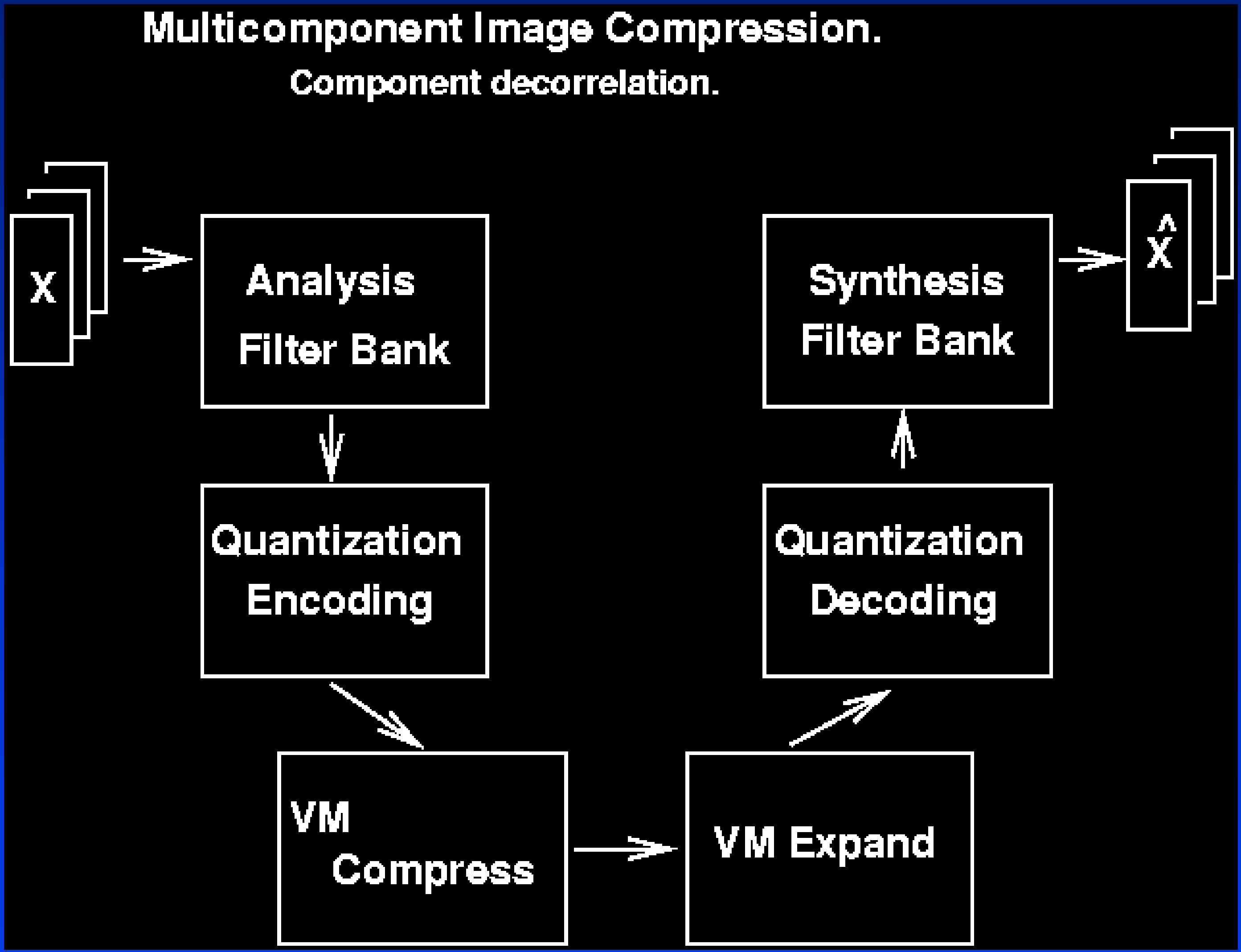
- We're getting respectable decorrelation coding gain (consistent with KLT Theoretical Coding Gain predictions) on extremely smooth data (e.g., Army atmospheric measurements).
- Decorrelation coding gain is non-existent for tomographic imagery, both medical and industrial.
- We see a little decorrelation coding gain in doctored images with a disproportionate amount of flat, noiseless background, but even then the achieved performance doesn't live up to KLT TCG predictions.
- At present we cannot recommend use of component-decorrelating transforms on tomographic imagery; the VM produces comparable results regardless of whether one uses a component decorrelation transform or not.

Experiments with Non-Symmetric Filters for Hyperspectral Component Decorrelation

- **Goal:** Determine whether non-symmetric (orthogonal in particular) filter banks are a practical alternative to linear phase filter banks for hyperspectral component decorrelation.
- **Motivation:** Conventional tools for hyperspectral component transformation (e.g., Fourier transforms, KLT) are orthogonal transforms, but restriction to linear phase filter banks would preclude use of orthogonal filter banks for component decorrelation in JPEG-2000. Orthogonality may be important for some applications, and it is desirable not to eliminate orthogonal filter banks without good reason.
- **Alternative:** Orthogonal filter banks could still be used and signaled via matrix representation, but this would incur much more signaling overhead than necessary, would not support efficient (i.e., lifted) implementation, and would preclude reversible implementation.
- **Experiments:** Run on a small sample of AVIRIS (Jasper) 224-band data. Several common orthogonal filter banks with 4 vanishing moments were implemented via circular convolution and compared against performance of 9-7 filter bank implemented via both symmetric extension and circular convolution.

Overview: Non-Symmetric Filter Banks Applied to Data Cube Outside of VM (using Matlab)

- Floating point Matlab filter bank output quantized prior to input to VM:



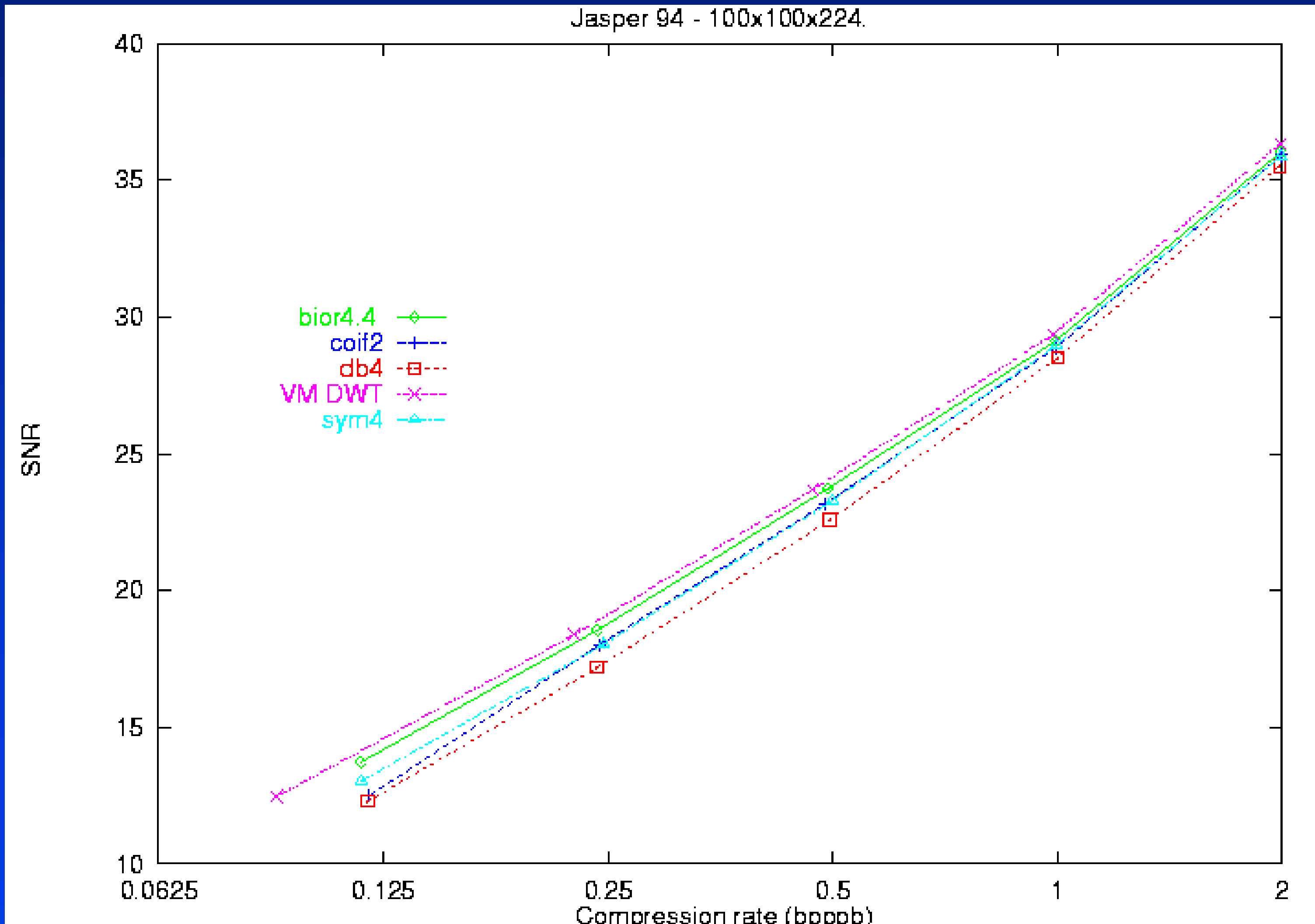
Theoretical Coding Gain Comparison

- Based on variances of AVIRIS DWT subbands computed via circular convolution. (9-7 filter bank result also based on circular convolution.)

Filter Bank	Coding Gain
9x7 (Biorthogonal 4.4)	29.89
Daubechies N=4	26.55
Symlet 4	32.39
Coiflet 2	30.51

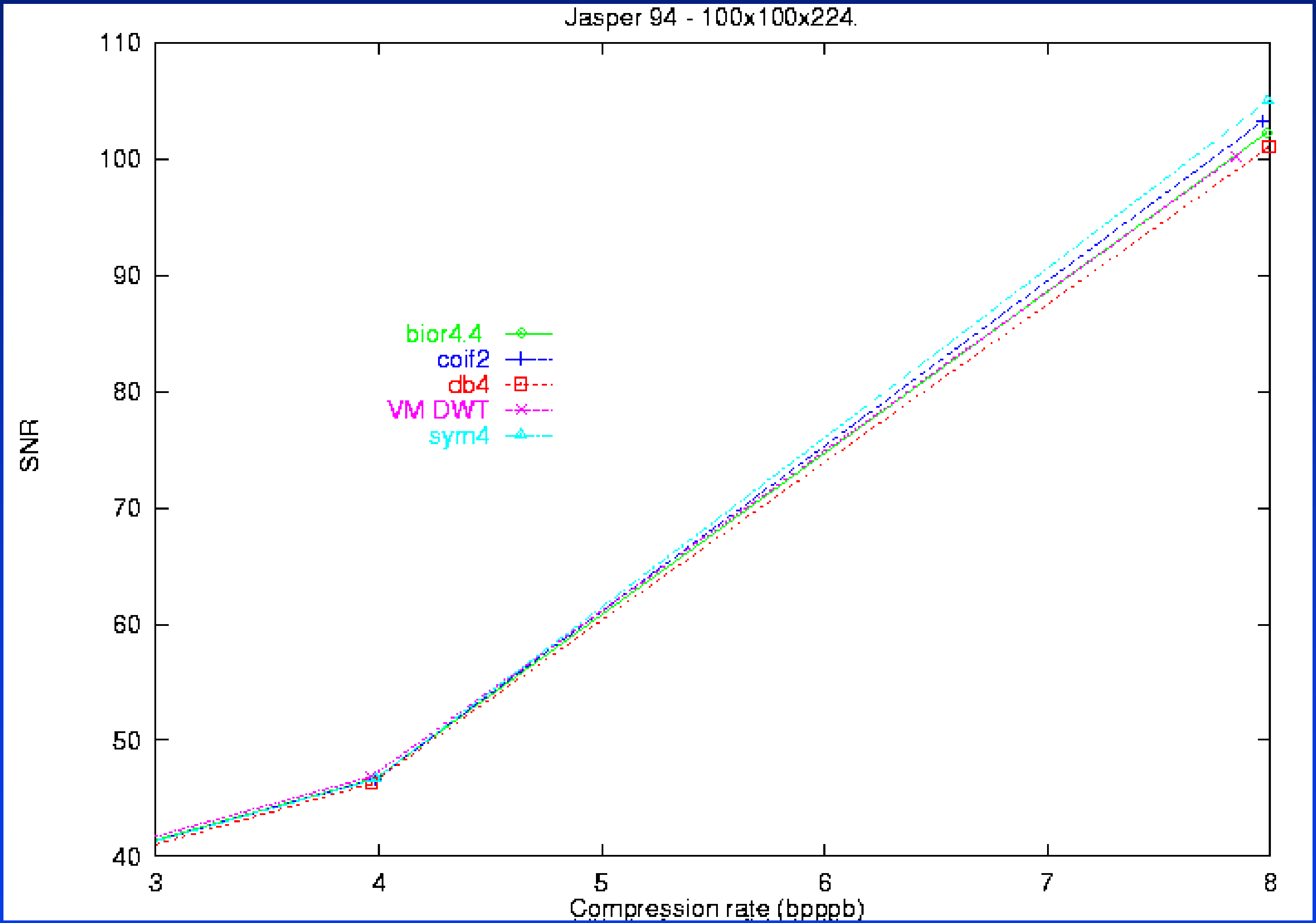
Rate-Distortion Comparison at Low Rates

- **Negligible advantage for symmetric extension (purple) vs. circular convolution (green) with the 9-7 filter bank:**



Rate-Distortion Comparison at High Rates

- 8-tap symlet & 12-tap coiflet actually do better than both 9-7 options at high rates:



Recommendations

- Figure out WHY decorrelation methods fail to yield meaningful coding gain on tomographic imagery, either industrial or medical.
- Add software implementation of non-symmetric filter bank component decorrelation to the VM to enable more thorough experimentation.
- Add an algorithm to Annex I for applying non-symmetric filter banks for component decorrelation via circular convolution. Use Annex G filter bank syntax for signaling.
- Enable signaling, application of multiple linear transforms for different subsets of a single multicomponent dataset.
- Consider expanding dynamic range for signaling quantization step sizes. This appears to be a problem for optimal rate allocation in some multicomponent applications.
- Fix guard bits bug in the VM.